Integrated Reliability in Non Volatile Memory Cell Design

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Introduction

Increasing integration of Non Volatile Memory (NVM) induces low injected charge quantity of about thousand electrons in modern flash memories [1]. Repeated write/erase operations affect dielectric sensitivity with dramatic effect on retention [2]. Indeed, the memory array reliability is affected since only one cell is defected. The oxide degradation is strongly depending with the thin oxide electric field [3]. Taking it into account during the design of a cell is of utmost importance to increase hardness [4, 5].

This study is focusing on Electrical Erasable Programmable Read-Only Memory (EEPROM) cell endurance behavior depending on tunnel oxide electric field, related with coupling ratio which is one of the major key of a new cell design. Indeed, increasing coupling ratio decreases applied voltage. Moreover, degradation prediction, after repeated write/erase operations, is attempted with Fowler-Nordheim parameters evolution study.

Results

In NVM, information is made of a charge trapped into the oxide or injected into a floating gate through a tunnel oxide. In EEPROM (Fig.1), the injection is controlled by a Fowler-Nordheim mechanism, and current, I_{FN}, is described by the following equation [6] :

$$I_{FN} = \alpha S E^2 \exp -\frac{\beta}{E} \tag{1}$$

Electric field, E, across the thin oxide is a function of cell's geometrical parameters and applied voltage. It depends on coupling ratio which is related to the different oxides capacitances (Fig.2), in erase mode, Ke :

$$Ke = \frac{Cpp}{Cox + Ctun + Cpp} \tag{2}$$

Simulation shows that paradoxically, an increasing coupling ratio increases the electric field and, in the same way, the degradation (Fig.3) [4]. In order to verify this assumption, we change areas without changing any oxides thickness. So, we realize samples with different coupling ratios, but with the same inter-poly capacitance Cpp in order to keep the same injected charge ΔQ_{FG} for a same threshold voltage window ΔV_T :

$$\Delta V_T = \frac{\Delta Q_{FG}}{Cpp} \tag{3}$$

Finally the changing parameters are *Cox* and *Ctun*. Write/erase cycling of these samples (Fig.4) shows that increasing coupling ratio decreases endurance as predicted. Degradation is located in the tunnel oxide where the electric field is high enough (>10MV/cm) to permit charge injection. This degradation could be taken into account in simulations, with the Fowler-Nordheim parameters (α, β) evolution during write/erase cycling. In order to quantify this evolution, we extract them from a large area capacitor (with the same oxide thickness than in the EEPROM cell) submitted to an equivalent cycling with constant electric field. Applying square pulses on capacitor is equivalent to apply optimized signal on EEPROM cell (Fig.5) [3]. Figure 6 shows the evolution of extracted parameters from capacitor versus the number of write/erase operations. Figure 7 shows the evolution of threshold voltage window simulated with these parameters compared with the one measured on EEPROM cell.

Discussion

Endurance test, performed on samples with different coupling ratios (Fig.4), confirms the assumption that degradation is related to electric field. The best way to reduce supply voltages, regarding endurance considerations, is not to increase the coupling ratio. The choice of coupling ratio in a new cell's design should result from a compromise between a high *Ke* value in order to use low supply voltages and reduce the pump charge area, and low *Ke* value to increase the cell's endurance.

Moreover, the best way to design a robust cell should be to include this degradation effect in the model. We start the endurance test fitting after 100 cycles [7] in order to reduce an eventual degradation due to measurement process, in this way the cell presents a significant degradation due to programming signals. From Fowler Nordheim parameters evolution (Fig.6), simulation results are in good agreement with the experimental endurance cell's degradation.

Conclusion

In the one hand, we demonstrate the paradoxical impact of coupling ratio on reliability because of the resulting electric field across the tunnel oxide. On the other hand, we extract the Fowler Nordheim parameters evolution during cycling on larger capacitor. At least, we have already shown that simulation of electrical behavior of a cell during design, improves considerably the functionality efficiency [5]. Modeling of Fowler Nordheim parameters during write/erase cycling will allow to improve cell's conception as soon as design.

This new cell conception methodology improve reliability, using simulation including degradation impact with optimized signals as soon as write/erase operations.

References

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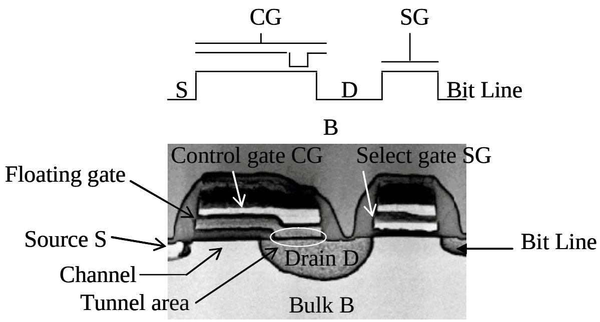

Figure 1 : EEPROM cell's cross section, contacts definition and associated electrical scheme.

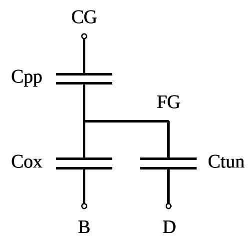

Figure 2 : EEPROM cell's sense transistor capacitances.

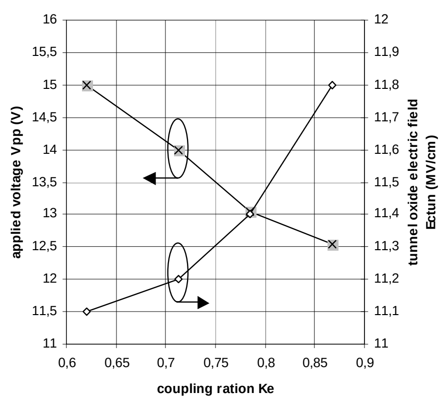

Figure 3 : Simulated applied voltage and thin oxide electric field versus coupling ratio [3].

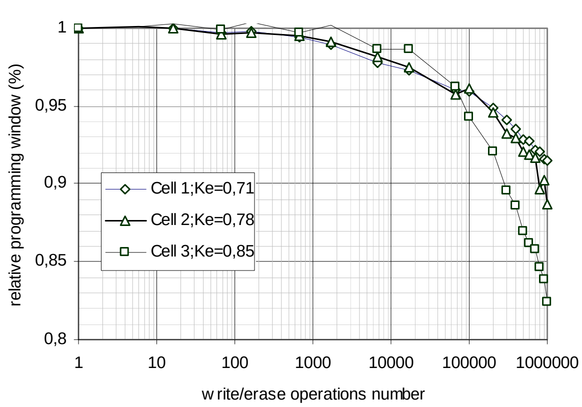

Figure 4 : Endurance test on cells with different coupling ratios.

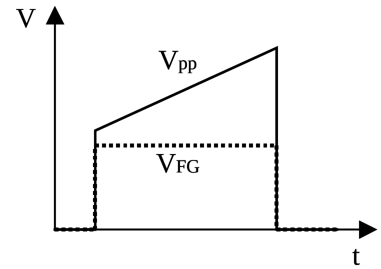

Figure 5 : Optimized signal, V_{pp}, and resulting floating gate voltage, V_{FG}.

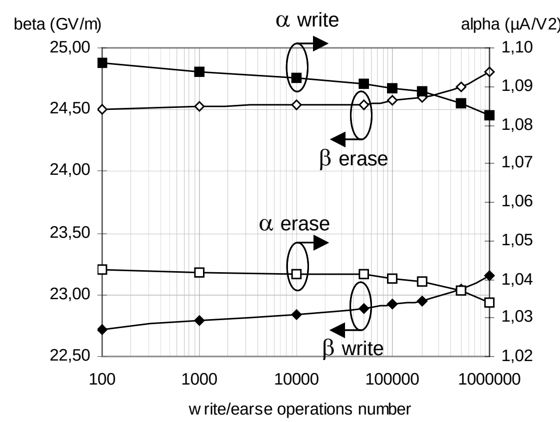

Figure 6 : Fowler Nordheim parameters evolution (extracted from large area capacitor).

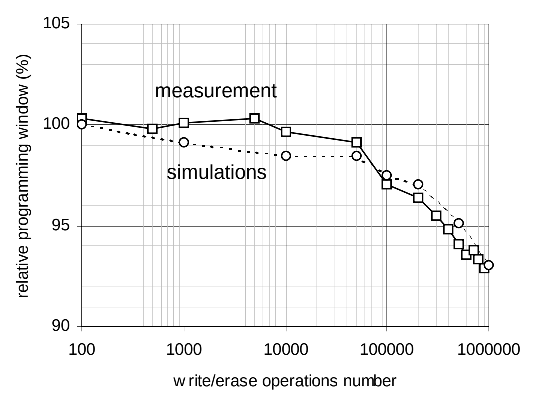

Figure 7 : relative programming window measurement (on EEPROM cell : straight line) and simulation (with Fowler Nordheim parameters extracted from capacitor : dashed line).